AN EVALUATION MODEL OF COMMUTER-TRAIN OPERATION SCHEDULE AND ITS APPLICATIONS

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1.PREFACE

The metropolitan region of Tokyo has 27 million population and 6,400 square km area, where 70% of 15 million daily passenger trips are carried by railway network of 2,070km in rout length. Besides transport capacity has been enlarged so far, commuter trains coming from outskirts to mid-city show still now tremendous congestion at peak-time (standing passenger density: 5 to 10 passengers per square meter) mainly forced by high demand concentration to peak time which is derived mostly from Japanese tight labor time system, and by still going sprawling of residence and increasing of office site demand.

These situation has been regarded as one of the most serious problems of Japanese transport policy and is now more exaggerated through the discussion on improvement of "quality of life" and acquired nation-wide interest. In addition to the physical improvement of transport capacity of railway networks such as multi-trackings, extension of train length and increasing of train frequency which have been carried out for years as orthodox countermeasures, over-all countermeasures have been proposed from short-term to long-term, from supply-side to demand-side (Figure-1).

This study focuses on the improvement of commuter train operation schedules as short-term supply-side countermeasures to accomplish more comfortable commuting, which would have complimentary effects for long-term investments.

2.COMMUTER TRAIN SCHEDULE AND PASSENGER'S BEHAVIOR

2.1.Existing study on train scheduling

Train Scheduling has been studied for long but only from the standpoint of the actual requests of planners in railway operators except classical basic studies. One is on the studies to establish efficient method to find feasible train schedules which would fit to the practical constraints such as running constraints, passing position, return constraints and so on. The other is to develop the control systems of train operation such as real-time monitoring, data restoration or adjustment of train schedule after unavoidable delays. Japanese consequent example for these two purposes are several computer-aided systems developed as DIAPS and COMTRAC etc. Apart from these matters additional request for study has been delivered newly from the already mentioned background.

[SUPPLY SIDE]

- more tracks
  - multi-tracking
  - new line construction
- more trains
  - more vehicles installation
  - train interval reduction
    - board/alight time reduction
      - many-door, large-door vehicle
      - both side board/alight station
    - track allocation improvement in stations
    - signal system improvement
- more vehicle floor area
  - longer train-set
  - double decker commuter vehicle
- better vehicle accomodation
  - improvement of seats
    - less seat vehicle (more space for standers)
    - more seat vehicle (better comfortability)
  - better accomodation
    - air-conditioner, in-vehicle equipment
    - more and better straps
- better train operation schedule
  - stop-pattern, train types, speed
- better station facilities for passengers
  - better transfer
  - smooth movement of passengers
- better financial system for investment
  - return of development benefit
  - return of density merit on industries

[DEMAND SIDE]

- distribution of demand
  - peak-load pricing, staggered hours
- smooth passenger flow
  - discount of initial fee for transfer
- demand management
  - satellite office, at-home work
  - distribution of centralized office allocation

Figure-1 Integrated countermeasures for commuter railway improvement

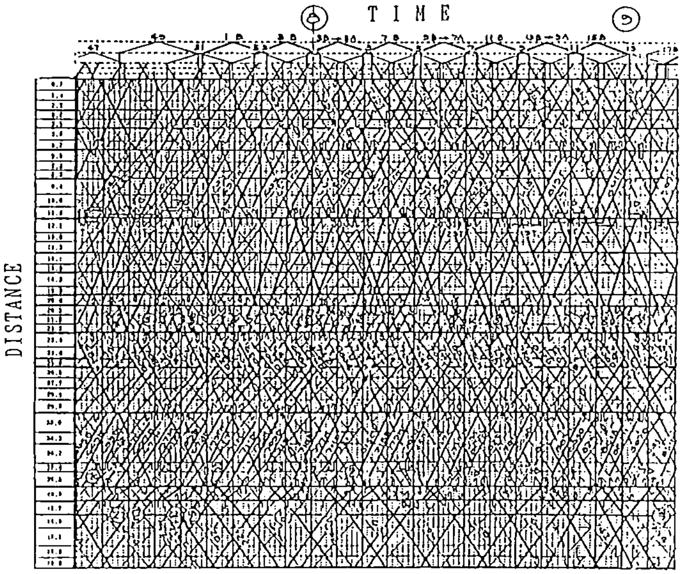


Figure-2 An example of commuter railway diagram

- to forecast traffic dimensions such as cross-section passenger flow by trains, transfer passenger number and so on, as the result of an alternative of train operation schedule
- to evaluate alternatives of train operation schedule from the standpoint of whole users' benefit or operator's cost and distribution of benefit among users
- to find the desirable train operation schedule pattern suited to demand pattern
- to evaluate the effect of infrastructure investment such as multi-tracking or improvement of stations through train operation services

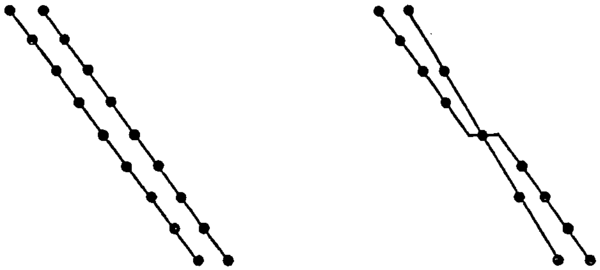
In the next chapter, an evaluation/forecast model will be developed to meet the first and the second purposes. The third and the fourth will be able to be studied through the model.

2.2.Variety of train operation schedule and its feature

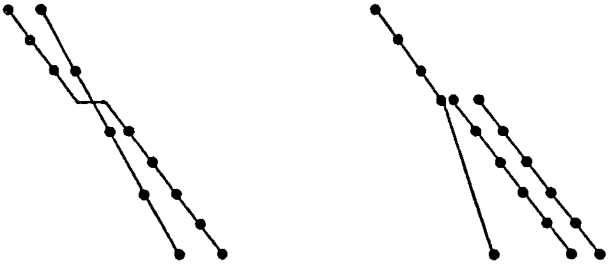
Train operation schedules are designed by "Meisterwerk" specialists in railway operators based on empirical knowledge acquired through trial and error considering transport capacity, speed performance, transfer convenience, congestion on board and in stations, required train sets number, man power, robustness against unusual situation, simplicity,... under constraints of passing, return and interval with given parameters which determine the running condition of trains and the features of station and lines. They have much variety on features actually as above mentioned points have normally trading-off characters. For example, station-skipping express train brings high quality of speed performance but at the same time local train's virtual speed must be reduced by passing. Train operation diagrams differ each other being influenced from each operator's standpoint or management policy and transport demand pattern. Figure-2 shows an example of commuter train diagram of suburban line in Tokyo which consists of several types of trains: local, semi-express and express with various stop pattern and operation intervals. After basic analysis of train diagram patterns on 15 suburban commuter railways in Japanese large cities, train diagrams are found to be roughly categorized to four types shown in Figure-3.

- Parallel type: the most trains can be set with the common train speed
- Separated local/express type: higher travel speed avoiding congestion on transfer-stations' platform
- Connected local/express type: higher travel speed and transfer convenience
- Regional stop-section type: each train types are specialized to specific passenger collection and distribution section, provide higher travel-speed but more transfer and wait time

These train operation schedules with much variety have not been



Parallel type Connected local/express type



Separated local/express type Regional stop-section type

Figure-3 Categolized train operation patterns

satisfactorily evaluated objectively from the standpoint how much these operation offers utility for passengers or which alternative of diagrams is the most suited.

2.3.Passenger's behavior and the framework of the study

How will be the framework of integrated evaluation of train operation schedule considering traffic demand. Showing in Figure-4, let inter-station origin-destination passenger demand volume as the input of transport demand side and train operation schedule as the input of transport supply side on a discussing line and time period (like peak one hour etc.). Problem is how passengers determine their ride train, transfer pattern between trains individually, how traffic flow like cross-section passenger volume on each trains or of transfer are derived as the result, and how passengers suffer transport disutility/cost consequently. When these matters can be forecasted by a rational way, gross summation of passenger disutility or its distribution among them will be used as the output indices for evaluation. Operator's cost for train operation is of course also important for users, as it should be transferred to users through a fare system. But this study does not mention its detail as it is comparatively easier to measure.

3.EVALUATION MODEL OF COMMUTER TRAIN SCHEDULE BASED ON TIME-SPACE NETWORK ANALYSIS

3.1.Time-space network and UE assignment model

To prepare a field for the reproduction and the forecast of passengers' train choice behavior, normal train diagrams which are drawn in two-dimensional space will be converted to plane network (Time-Space network) with directional links expressing passenger flow paths (Figure-5). Network links consist of board link, alight link, transfer link, wait link, on board link and pass link, which all correspond the link cost functions meaning the transport disutility for passengers. Now the passenger flow/cost problem on a train diagram is translated into an inter-station OD flow assignment problem

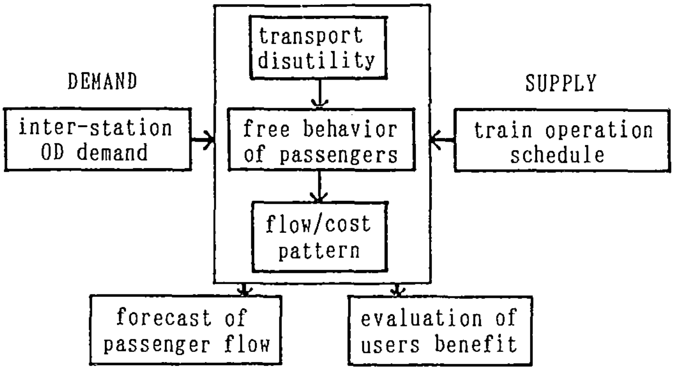


Figure-4 Framework of study

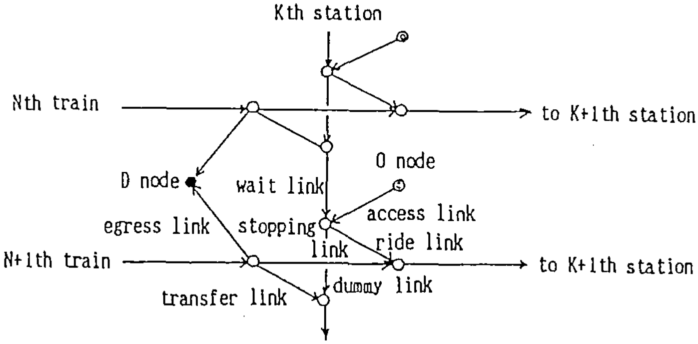


Figure-5 An example of time-space network on the static network. For this assignment user equilibrium principle is adapted, as (1)link cost function on board has flow dependent feature when in-vehicle congestion is considered, and (2)the assumptions for user equilibrium assignments: rational behavior under full knowledge and less varied user's preference, are all suited to the commuter transport.

3.2.Estimation of passengers' disutility function

As disutility function which derives preferential behavior of passengers cannot be measured directly, it is acquired through the calibration so as to minimize the square summation of difference between observed and estimated link flows by the UE model. The disutility function is assumed as following formula,

$$D_u = t_b + c \cdot x/(d \cdot cap - x) \cdot t_b + a \cdot t_w + b \cdot t_n$$

D_u :link transport disutility
t_b :ride time
x :link flow
cap:passenger capacity on train
t_w :wait time
t_n :transfer variable (1 or 0)

where the first item means travel time disutility, the second congestion on board, the third wait time and the fifth is transfer disutility. The parameters a, b, c and d were at first estimated as follows in one of the suburban commuter lines in Tokyo through passenger flow observation:

$a=1.6$, $b=30$ seconds, $c=0.22$, $d=3.5$

Figure-6 and Figure-7 are a part of the estimated flow pattern and the fitness of observed and estimated flows under the optimum parameter vector respectively. The verification test were fulfilled in several other commuter railway lines in Tokyo and Osaka. The applicability, reliability and transferability of the model and the parameters were confirmed from practical point of view. Figure-8 shows the estimated congestion disutility function for unit ride time.

4.APPLICATION OF THE EVALUATION MODEL

4.1.Evaluation of train operation schedule in existing lines

Now we can evaluate train operation-schedule by adapting the estimated model to any lines only if inter-station OD flows are given. Figure-9 shows the sketches of train diagrams of three existing examples. Two normalized indices are proposed as follows for the relative comparison among lines irrespective of their different traffic demand or the scale of the lines.

$$TDI = \sum_{l} D_{ul} \cdot X_l \Big/ \sum_{rs} q_{rs} \cdot (L_{rs}/v_{ref})$$

$$DDI = \underset{rs}{Var}(TDI_{rs})$$

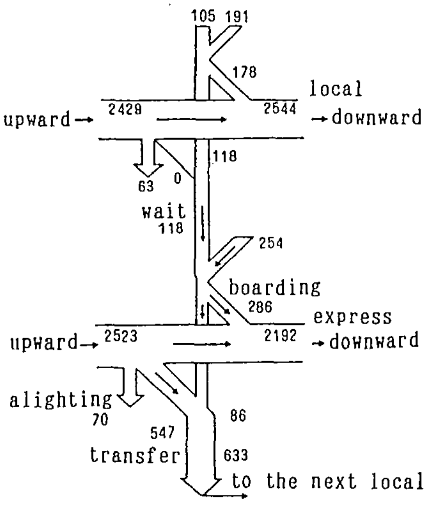


Figure-6 A part of the estimated network flow

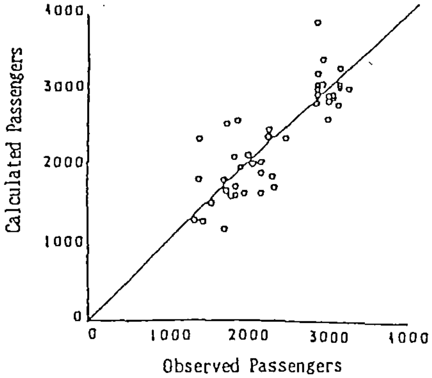


Figure-7 Fitness of observed and estimated flows

TDI :total disutility index
DDI:disutility distribution index
D_{ui} :disutility on link i
x_i :flow on link i
q_{rs} :OD flow from r to s
L_{rs} :distance between r and s
v_{ref}:referential speed (60km/h)
TDI_{rs}:total disutility index for r-s passengers
Var(·):variation operator

Among these three examples the train diagram A and B (regional stop section type) can be said comparatively more recommendable than C (local/express type) when the gross disutility shown by TDI in Figure-10 is focused. Between A and B, B is relatively inferior to A from the standpoint of impartiality among passengers as DDI of B is 70% higher than that of A. The reason is the service level for passengers boarding from rather near stations to the terminal is worse (Figure-11).

4.2.Estimation of practical evaluation formulas

The above mentioned methodology requires sophisticated calculation on computers and some CPU time, practical evaluation formulas were developed to derive the rough result of train schedule evalua-

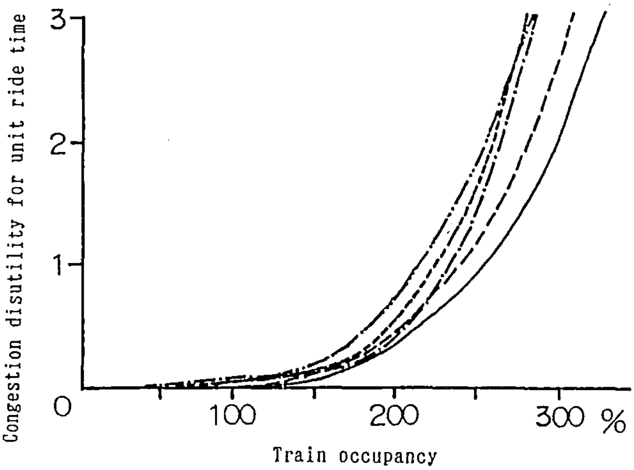


Figure-8 Estimated congestion disutility functions

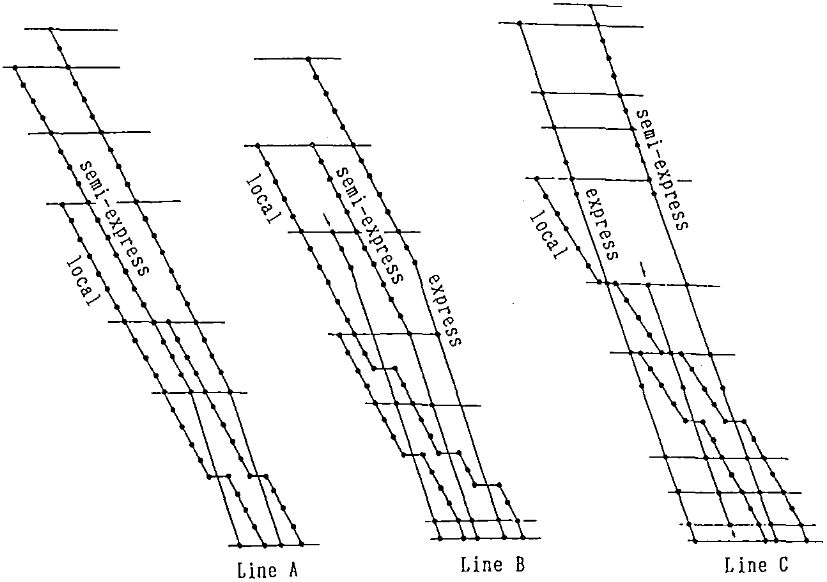


Figure-9 Sketches of three sample train digrams

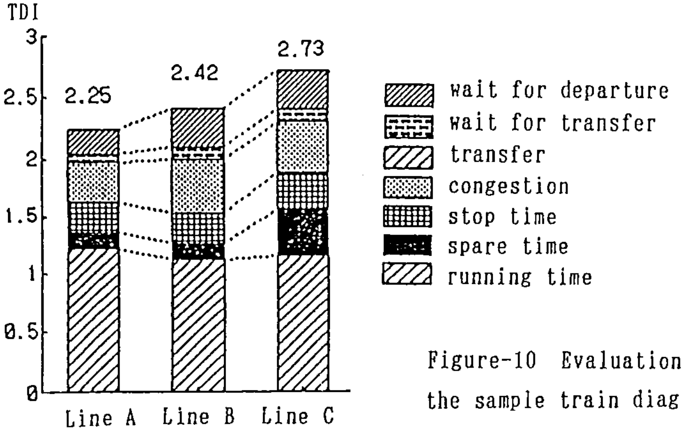


Figure-10 Evaluation of the sample train diagrams

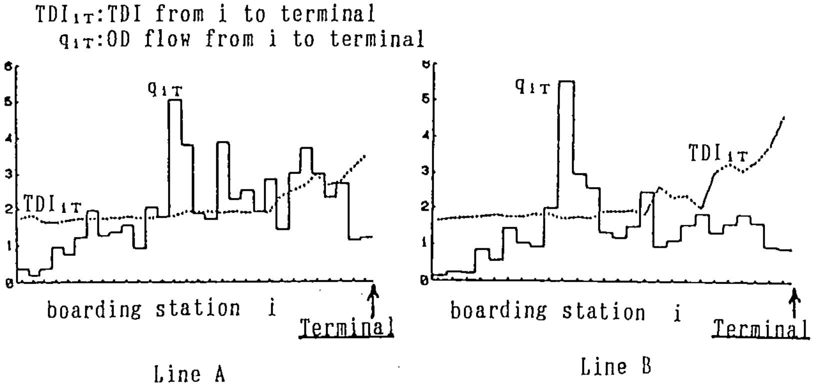


Figure-11 Variation of total disutility index among boarding stations

tion by rather simple calculation for practical use. At first 66 feasible model cases were prepared with three levels of passenger demand, four types of inter-station OD pattern and ten types of train operation pattern. Secondly, 86 easy-calculated indices were defined to express characteristics of transport demand, supply and their interactions. Thirdly, the assignment model was applied on 66 model cases to derive user's disutility (on board, in station) under already estimated parameters. Lastly, practical regression formulas which can explain user's gross disutility only by easy-calculated indices were estimated. Figure-12 shows the results.

$U=U_{OB}+U_{IS}$

$U_{OB}=Q_L\cdot(1/V_N)\cdot f$

$U_{IS}=Q\cdot d\cdot g$

$f=0.777\cdot k_c^{-0.562}\cdot k_q^{-0.270}\cdot S_{c1}^{0.169}$

$g=2.15\cdot k_c^{-0.117}\cdot k_q^{0.252}\cdot S_{c2}^{-0.023}\cdot S_{c3}^{0.624}\cdot S_t^{-0.035}$

U :gross disutility (passenger·hours)
U_{OB}:on board disutility (passenger·hours)
U_{IS}:in station disutility (passenger·hours)
Q_L :gross transport volume (passenger·kms)
Q :gross transport volume (passengers)
d :average train interval (hours)
V_N :average train speed (km/h)
k_c :transport capacity ratio
k_q :stop time ratio
S_{c1}:standard deviation of cross-section transport capacity ratio
S_{c2}:standard deviation of cross-section transport capacity
S_{c3}:standard deviation of departing capacity among stations
S_t :standard deviation of stop ratio among trains

Figure-12 Practical evaluation formulas

4.3.Correspondence of Train operation pattern and demand pattern

At the same time, the fitness between OD demand pattern and train operation types were checked on the above mentioned model-case analysis. As the results, in radial direction commuter train lines, which connect wide-spread suburban residential region to CBD terminal and is predominant in large metropolitan railway system, the regional stop section type operation is most suited from the standpoint of gross users disutility. Additionally, among regional stop section types, express trains should be more emphasized and set on when passenger's travel distance and demand level are more increased.

On the contrary, in-city lines with plain inter-station OD patterns, simple parallel operation is suitable.

4.4.Development of computer-aided evaluation system of train schedule

Based on these theoretical and practical studies, a computer-aided evaluation system was developed to satisfy the practical request for evaluation, from railway operators and public transport policy planners. This software system IEDIS (Integrated Evaluation System for Train Diagram Scheduling) can be operated on general-purpose computers following the design process of train diagrams shown in Figure-13 and Figure-14. One of railway operators in Tokyo just has determined their newly revised train diagram after doing the evaluation of several alternatives introducing the viewpoint to minimize users disutility by the aid of IEDIS.

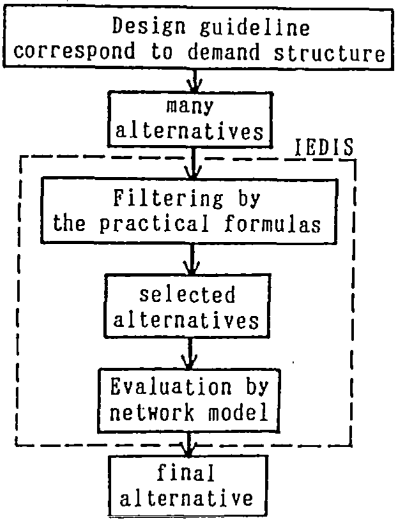


Figure-13 Design process of train operation schedule

[Data Input]
- station codes, distances, etc.
- inter-station OD demand table
- numerical train diagram data

[Condition] Input:
- parameters of the disutility function
- parameters of operator's cost function
- arrival-time constraints of passengers
- calculation mode
- convergence criteria

[Output]
- flow pattern forecast
- gross disutility and its contents
- TDI and DDI

Figure-14 Input and output of IEDIS

5.CONCLUSIONS

1)The theoretical framework based on time-space network analysis was proposed to evaluate train operation schedule objectively, considering passenger's benefit and to forecast flow patterns.
2)The model was applied on many existing lines in Japanese commuter railway networks to estimate the model parameters. Applicability and transferability of the model was verified.
3)The practical formulas were delivered through model case analysis for rough evaluation.
4)Fitness of the train operation types to the inter-station demand patterns was checked and the characteristics of suitable operation types were recommended.
5)The computer-aided evaluation/forecast system of train schedule (IEDIS) was developed.

BIBLIOGRAPHY

IEDA,H., et al..Commuter's benefit evaluation of train scheduling by network user equilibrium model.Infrastructure planning review No.6.Japan:Japan society of civil engineers,1988.pp177-184
SHIDA,K., et al..A study of transferability of parameters of railway commuter's disutility function.Proceedings of infrastructure planning No.12.Japan:Japan society of civil engineers,1989.pp519-525

FURUKAWA,A., et al..An analysis of train scheduling pattern and user's benefit.Infrastructure planning review No.7.Japan:Japan society of civil engineers,1989.pp131-138

IEDA,H., et al..Evaluation of user's benefit on train scheduling by model case analysis.Infrastructure planning review No.8.Japan:Japan society of civil engineers,1990.pp217-224

IEDA,H..Evaluation of transport congestion cost in commuter railways and its applications.Journal of the faculty of engineering, the university of Tokyo(B) Vol.XLI, No.1. Japan: University of Tokyo,1991.pp59-71

NAGAI,K., et al..A model for the choice of train scheduling pattern on commuter railway lines which is fitted to the characteristics of the demand.Infrastructure planning review No.9.Japan:Japan society of civil engineers,1991.pp149-156

IEDA,H..Computer-aided evaluation system of train operation schedule -IEDIS-, Japanese Railway Engineering Vol.30,No.4. Japan: Japan railway engineer's association,1992